

LA-UR-21-21371

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Title: MgB2 for SRF Cavities

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Intended for: Virtual workshop called Snowmass Workshop. To be presented on 17 February 2021.

Issued: 2021-03-05 (rev.1)

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MgB₂ for SRF cavities

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Outline

- Introduction
- Comparison between Cu, Nb, Nb₃Sn and MgB₂
- A brief current status of MgB₂ development for SRF cavities
- What needs to be done for HEP
- Other applications

Introduction

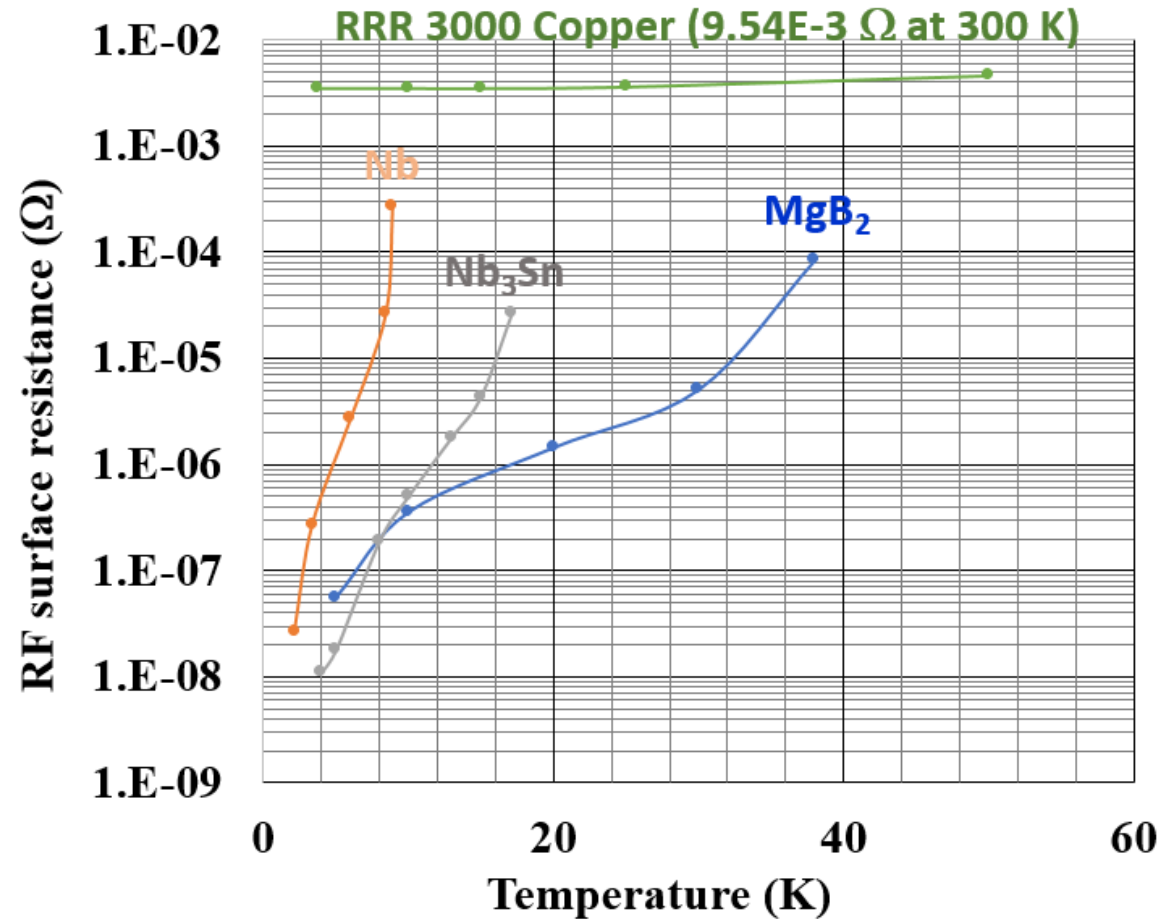
- It has been 20 years since MgB_2 was discovered to be superconductive at 39 K in Japan in 2001. There will be a special issue on MgB_2 in a Japanese journal Teion-Kogaku (Low Temperature Engineering). I will be writing an article “Application of MgB_2 for Superconducting RF Cavities” (in English). It will be published in November 2021 or January 2022. I plan to share it with SRF community after I submit it by the end of June 2021.
- Due to its significantly higher T_c compared to Nb (9 K) and Nb_3Sn (18 K), MgB_2 has been an interesting material to explore. This talk will not mention the progress of MgB_2 , but will show the comparison with Nb, Nb_3Sn and Cu when a 1.3-GHz TESLA type SRF cavity coated with MgB_2 is successfully developed to discuss pros and cons of MgB_2 .

Prediction of B_{sh} and corresponding E_{acc} for an electron accelerator with Nb, Nb_3Sn and MgB_2 [based on Catelani and Sethna, Phys. Rev. B78 (2008) 224509]

Material	B_c [mT]	B_{sh}/B_c	B_{sh} [mT]	Corresponding Accelerating Gradient* ¹ [MV/m]
Nb at 2 K	191	1.2	229	57
Nb_3Sn at 2 K	529	0.842	445	111
Nb_3Sn at 4 K	509	0.828	421	105
Nb_3Sn at 10 K	373	0.784	292	73
MgB_2 at 2 K	433	0.845	366	92
MgB_2 at 4 K	429	0.842	361	90
MgB_2 at 10 K	405	0.823	333	83
MgB_2 at 20 K	320	0.789	252	63

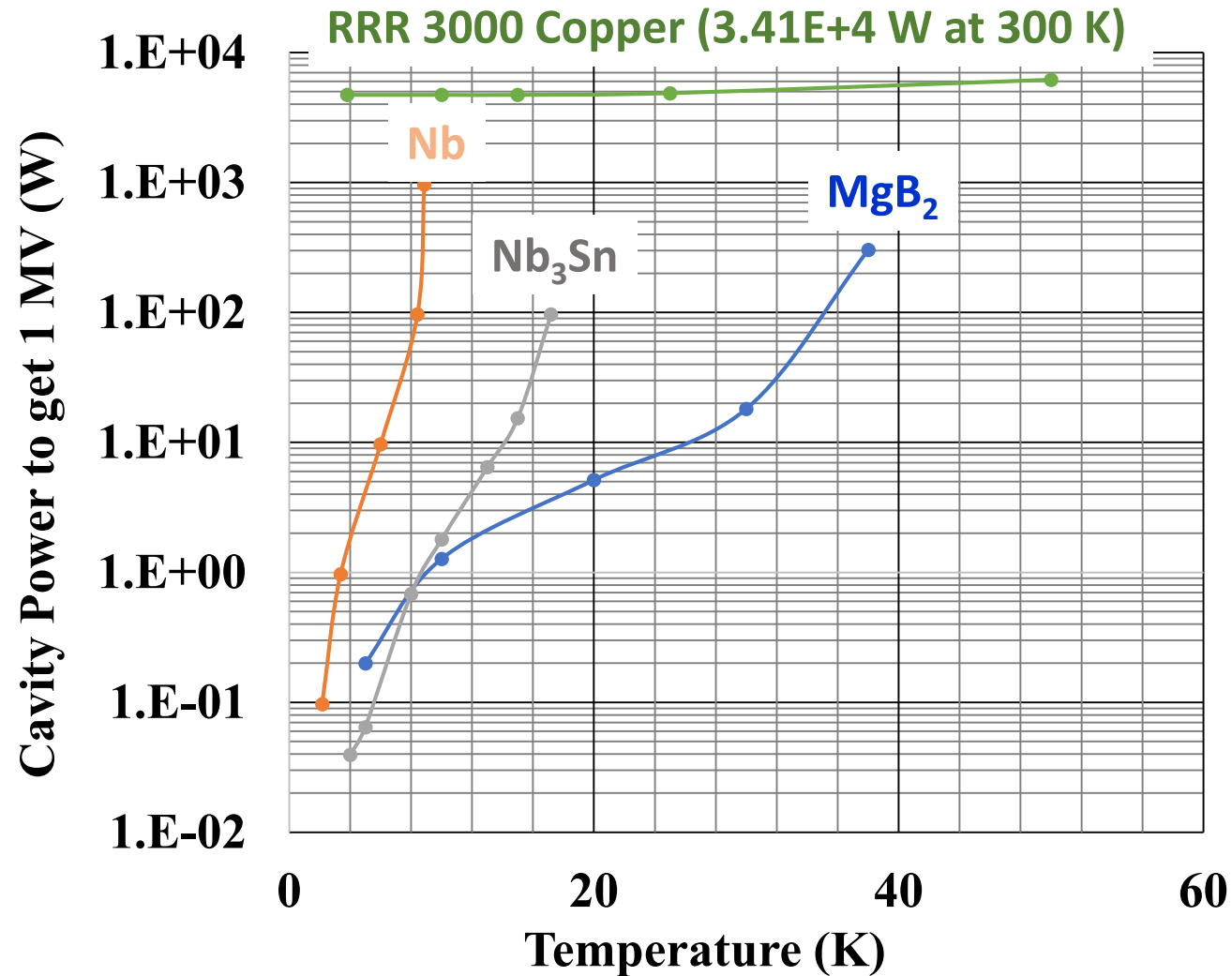
*¹Assuming 4 mT/(MV/m), which is typical for an electron accelerator.

Intrinsic RF Surface resistance at 1.3 GHz with Cu, Nb, Nb₃Sn and MgB₂ as a function of temperature [1-4]. Cu cavity $R_s \propto f^{2/3}$ at low temperatures was used.



- Up to ~8 K, Nb₃Sn is better.
- A good potential to operate the cavity at 20-30 K with cryocoolers.

Cavity power to get a 1 MV electron beam with a 1.3-GHz 9-cell cavity.



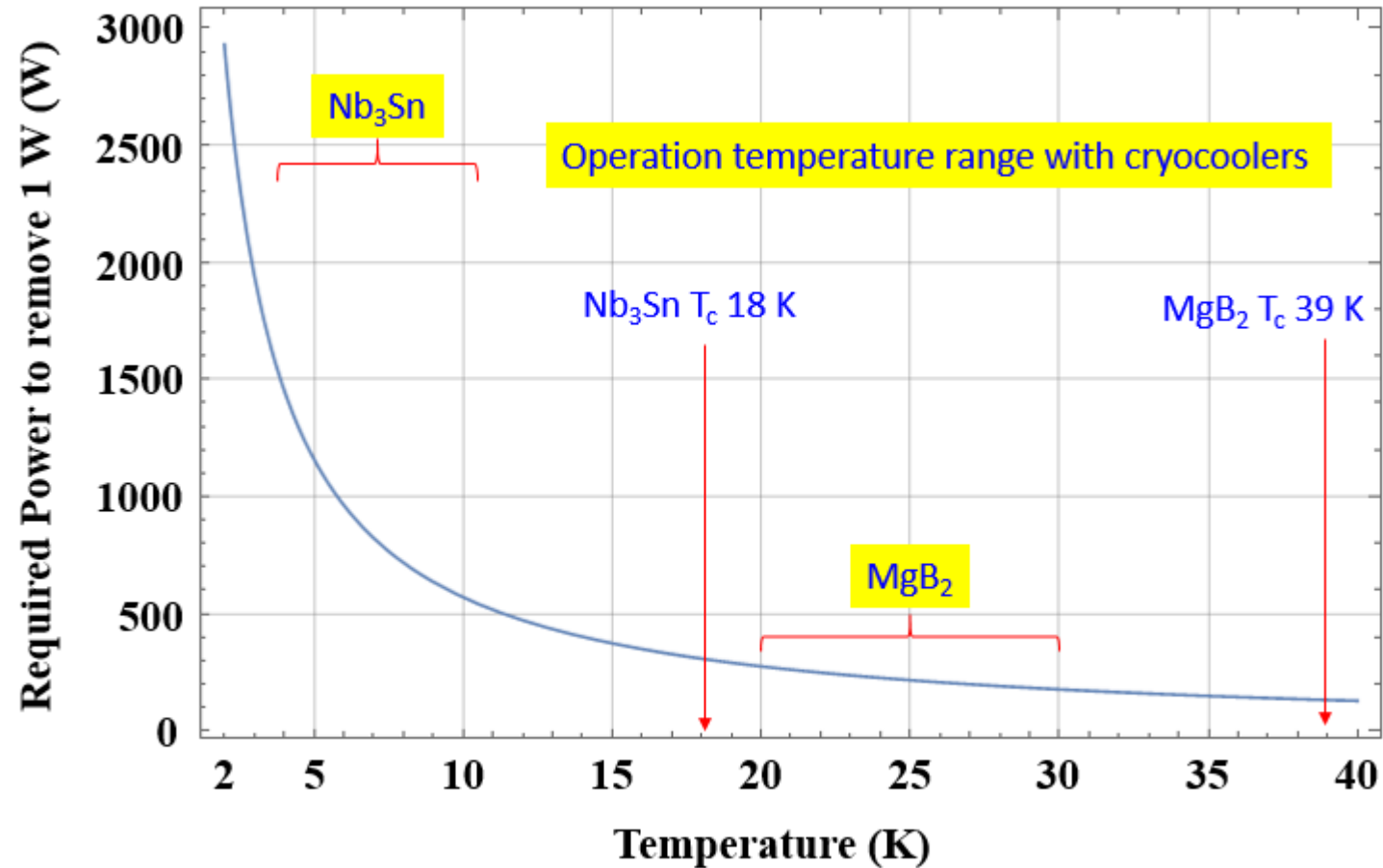
In the case of 1.3 GHz TESLA
shape 9-cell cavity

$G = 270 \, \Omega$

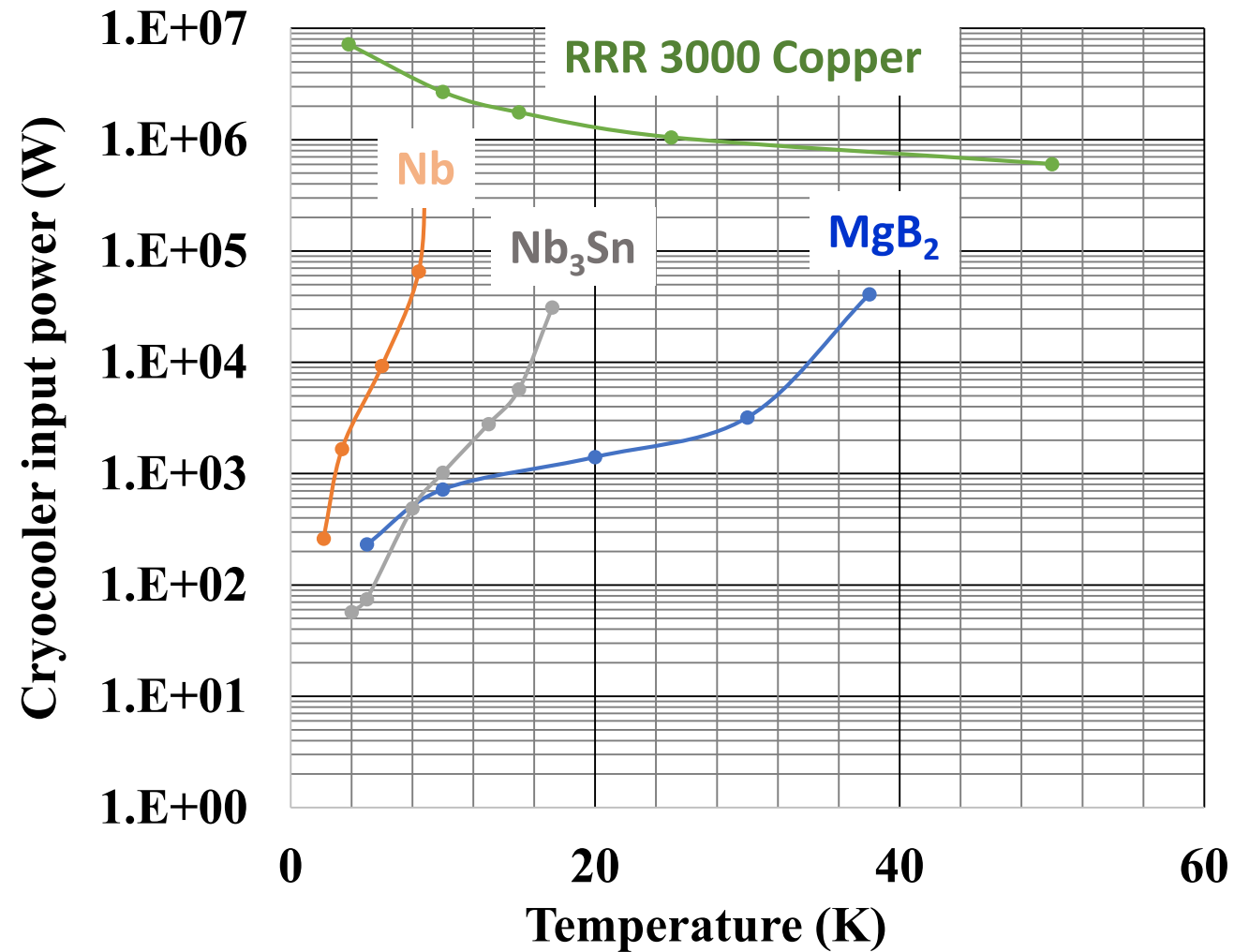
$R/Q = 1036 \, \Omega$,

$$P_{cav} = \frac{V^2}{\frac{R}{Q} \cdot Q_0} = \frac{V^2}{\frac{R}{Q} \cdot \frac{G}{R_s}}$$

Required power to remove 1 W as a function of temperature based on 5% Carnot efficiency. 3 kW is required at 2 K vs. 300 W at 20 K.



Cryocooler input power required for the 1 MV electron accelerator with a 1.3-GHz 9-cell cavity based on 5% Carnot efficiency. Combination of the previous 2 slides.

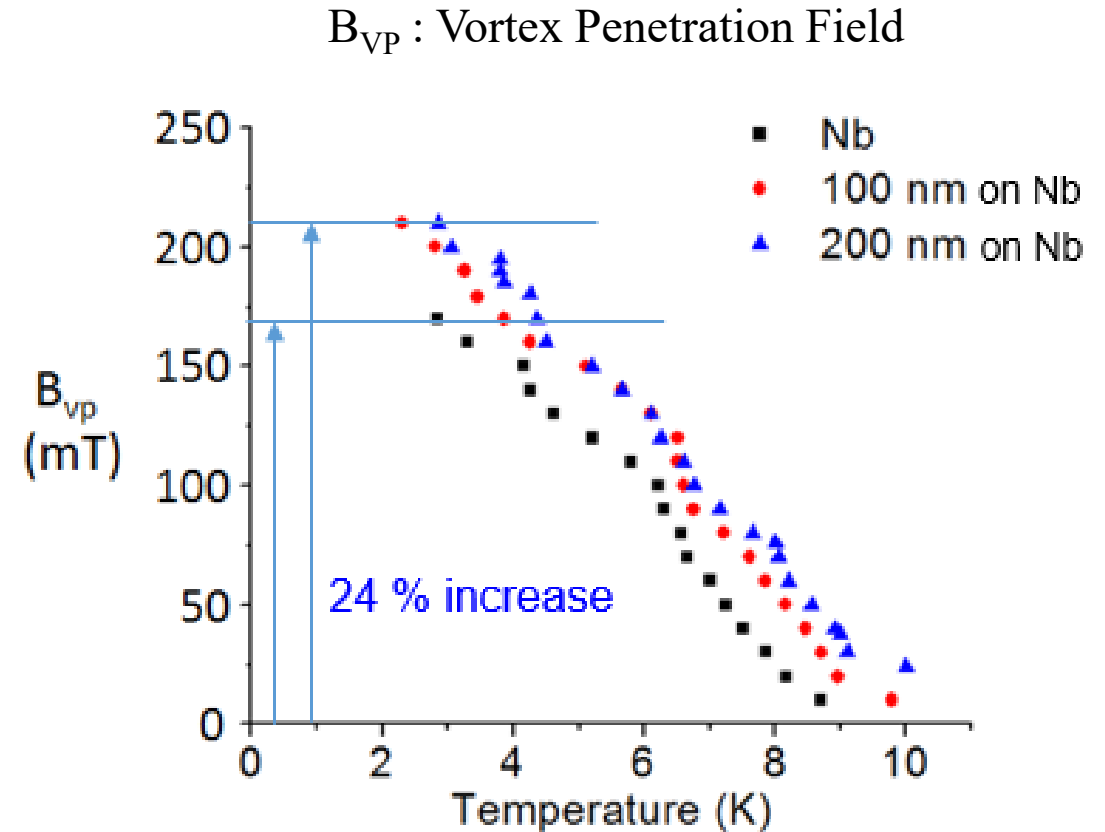


Current status of MgB₂ coating development for SRF cavities

- Hybrid Physical Chemical Vapor Deposition (Temple U.)
 - Flow B₂H₆ gas while Mg is vaporizing
 - Status
 - 3-GHz Cu cavity has been coated and tested at JLAB. ~36 K transition was observed but Q is higher than expected.
 - Seeking funding.
- 2-step coating (LANL)
 - Coat B layer by flowing B₂H₆ gas, then react it with Mg vapor (LANL)
 - Status
 - Reaction tests with Mg vapor using the B samples coated on Sapphire and Nb coupons taken from 1.3-GHz single-cell cavity surfaces have been performed and resulted in all superconducting MgB₂ films with T_c ranging 33-38 K. Coating on Cu has not been tried.
 - A new coating system to coat a 1.3-GHz cavity is being built. To be built by June or July 2021.
- ALD (ANL)
 - Proprietary
 - Aiming at lower temperature uniform coating. Good for sophisticated structures.
 - Seeking funding.

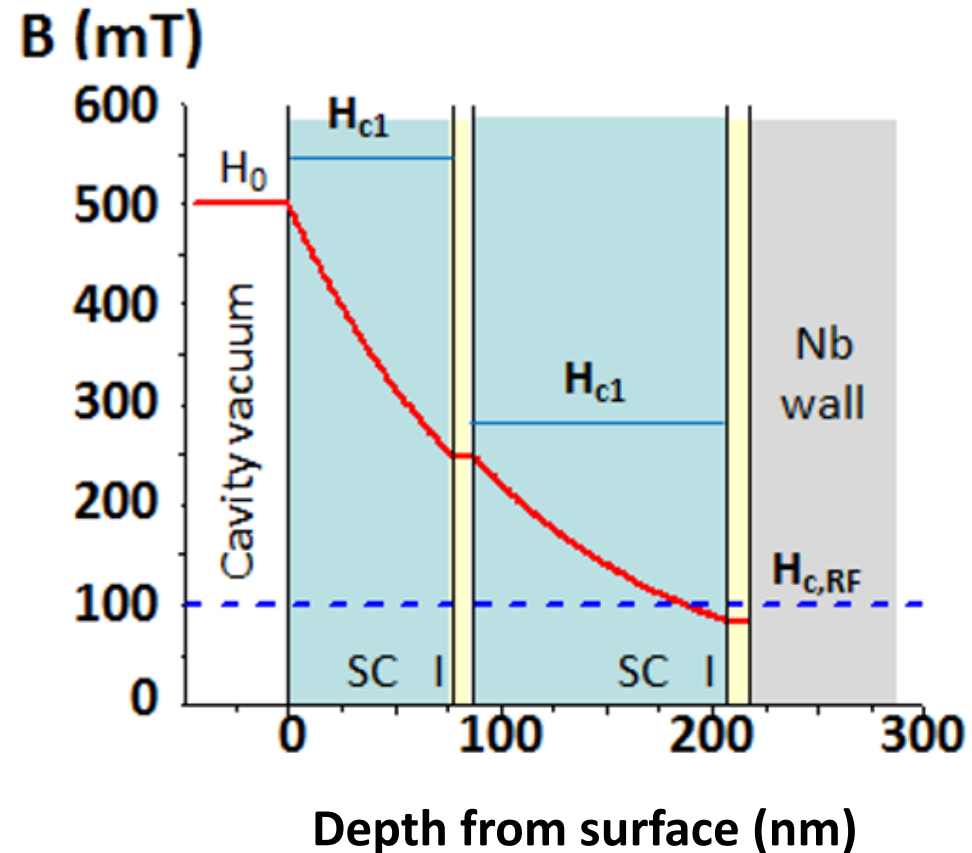
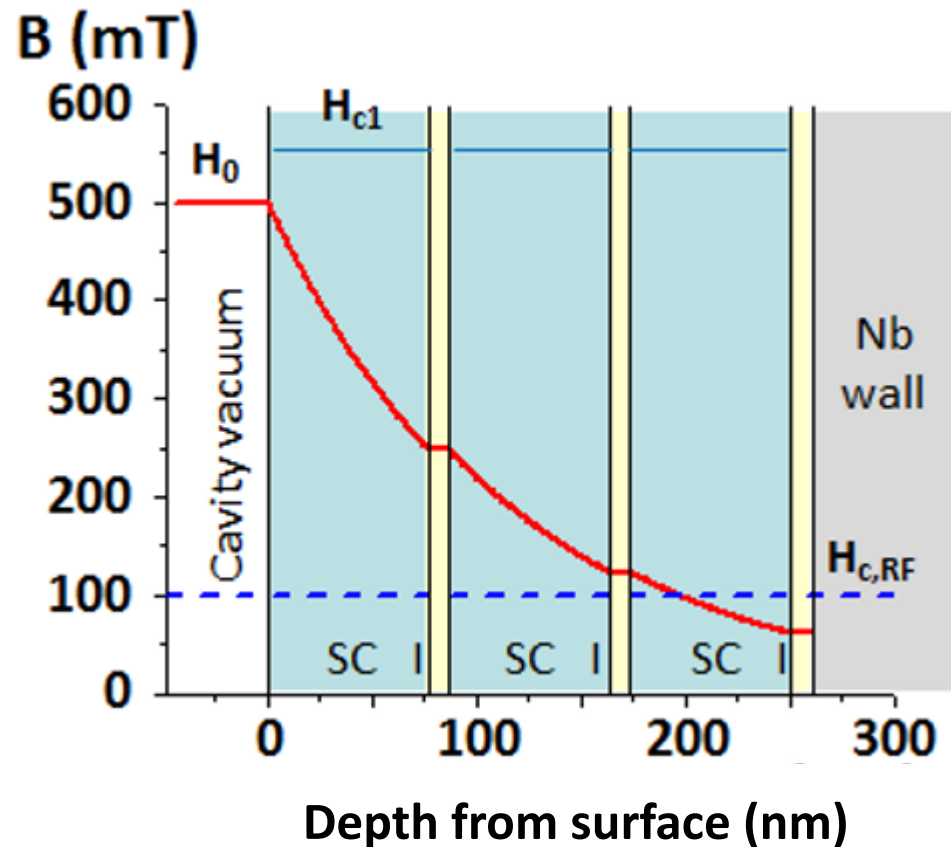
What needs to be done for HEP

- To raise the gradient of Nb cavity by thin MgB_2 coating.
 - $\sim 24\%$ increase in surface field might be possible as shown on the right.
- So, what about coating 100-200 nm thick MgB_2 on Nb cavity to see if this could occur?



[Teng Tan et al., Scientific Reports 6 (2016) 35879]

Using the fact that H_{c1} goes up with the film with thickness $\leq \sim$ penetration depth (~ 110 nm), E_{acc} of 125 MV/m with 2- or 3-layer MgB_2 coating might be possible



[Tajima et al., SRF2011, p. 287]

Other applications

- Since there are higher-cooling-capacity cryocoolers available at 20-30 K as shown below, MgB_2 cavities might be more suited than Nb_3Sn for industrial applications such as the treatment of sludge, waste water, flue gas and medical waste [5].

Table: Maximum cooling capacity of a cryocooler from Sumitomo and Cryomech.

Manufacturer	model	4 K	10 K	20 K	30 K	40 K
Sumitomo	RDK-415	1.5 W				
Sumitomo	CG310SC	5 W				
Sumitomo	RDK-415D		15 W			
Cryomech	AL630			100 W	190 W	270 W

Thanks for your attention!
Any questions or comments?

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